



USAF PRAM PROGRAM FINAL REPORT



INCORPORATION OF A LINEAR DRIVE CRYOGENIC
COOLER INTO THE AN/AAR-44 INFRARED WARNING
RECEIVER

Warner Robins Air Logistics Center
Directorate of Electronic Warfare
Special Programs Division
Electro Optical Engineering

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Approved for public release; distribution is unlimited

Approved by:

A handwritten signature in black ink, appearing to read "William P. Hallin".

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1. EXECUTIVE SUMMARY

The cryogenic coolers used in many infrared systems are the systems' Achilles heel in terms of reliability. We demonstrated a new technology linear drive cooler in an AN/AAR-44 missile warning receiver. Although this modification will not be fielded in the AAR-44, many optically guided missiles, targeting systems, night vision devices, and commercial thermal imaging systems employ similar cooled detectors. We present this report in the hope that the results will be useful to some of the numerous other systems that employ cryogenic coolers.

The AAR-44 is an electro-optical system used on about 100 specially equipped C-130 and C-141 aircraft. When designed in the late 1970s, it employed a state-of-the-art sterling cycle rotary drive cryogenic cooler. Production in the 1980s used an improved reliability rotary cooler, incorporating better processes and materials and a temperature control circuit. However, the cooler still contributed half of the failures and most of the maintenance cost. WR-ALC/LNXEA initiated this project when a new generation of off-the-shelf linear drive coolers became available in the late 1980s. Discussions with the AAR-44 contractor, Cincinnati Electronics, revealed that a new insulating dewar (thermos bottle) would further enhance reliability.

Under this project, Cincinnati Electronics selected a commercially available linear cooler and designed a new dewar. The contractor then integrated the new components into an AAR-44 sensor unit, performed reliability analyses, and completed performance and environmental testing. LNXEA managed the project and performed the cost analysis.

The modifications raised the sensor unit reliability from 107 to 153 hours lifetime average mean time between failures, while maintaining all performance parameters. The project cost is \$1,620,000 for a projected return on investment of 2.1.

Although this project met all its technical objectives, the AAR-44 users did not fund implementation. The customers are willing to live with the current reliability and, instead, are funding a false alarm reduction program. We plan to continue to monitor developments in anticipation that a future cooler will have benefits worthwhile to our customers.

2. INTRODUCTION

Most infrared systems have to be cooled to cryogenic temperatures to maintain their sensitivity. Unfortunately, the cryogenic coolers usually used are the systems' Achilles heel in terms of reliability. This project demonstrated an enhanced reliability AN/AAR-44 system incorporating a new linear drive cryogenic cooler. Although this modification will not be fielded, we present this report in the hope that the results will be useful to some of the numerous other systems that employ cryogenic coolers.

The AAR-44 is an electro-optical system that installs on the bottom of the aircraft where it scans for the infrared signals from hostile missiles. When designed in the late 1970s, it employed a state-of-the-art sterling cycle rotary drive cryogenic cooler. Production in the 1980s used an improved reliability rotary cooler, incorporating better processes and materials and a temperature control circuit. However, the cooler still contributed half of the failures and most of the maintenance cost. Recognizing that cooler technology was evolving, WR-ALC/LNXEA, from the onset of receiving responsibility for the AAR-44, started planning to implement the next generation of coolers. WR-ALC/LNXEA monitored the state-of-the-art of coolers, and initiated this project when the new linear drive technology became sufficiently mature.

This project was managed by WR-ALC/LNXEA (formerly WR-ALC/MMRRIS), which is the engineering office for the AAR-44 and several other electronic warfare systems. Mark Scott, currently a major at AFOTEC, initiated this project. He directed the achievement of the technical requirements and made a determined effort towards implementation. The tasks were accomplished by Cincinnati Electronics under contract F09603-91-C-0646. The author was responsible for overall AAR-44 engineering and assumed this project after Major Scott left WR-ALC/LNXEA.

3. TECHNICAL INVESTIGATION

Task #1 Analysis

Statement of the Problem

The reliability and maintainability Achilles heel of the AAR-44 missile warning receiver, and indeed most sensitive infrared receivers, is the cryogenic cooler. However, the investigation prior to the beginning of this project revealed several makes and models of cryogenic coolers, with promise to significantly improve the AAR-44's reliability. Therefore, task one was initiated to select the best cooler and estimate its impact on the AAR-44. Also, changing the dewar design from glass to metal held promise to increase the choice of coolers, so this task included a preliminary design for a metal dewar.

Investigations and Findings

The AN/AAR-44 Infrared Warning Receiver (IRWR), like many infrared systems, employs a detector that must be kept extremely cold to be sensitive to infrared light. Many optically guided missiles, targeting systems, night vision devices, and commercial thermal imaging systems employ similar cooled detectors. Some systems employ high purity compressed gas or cryogenic fluids like liquid nitrogen to chill the detector, but many, including the AAR-44, use self-contained refrigerators. Systems that use cryogenic coolers offer distinct logistical and portability advantages. To reduce the need for cooling, these systems use dewars (thermos bottles) to insulate their detectors. However, the coolers and dewars are usually the only significant mechanical devices in an otherwise highly reliable electronic system, so managers of these systems are keenly interested in improving the coolers' reliability.

The AN/AAR-44 is an airborne missile warning system that continually searches the environment, while tracking and verifying missile launches. It warns the aircrew of the positions of incoming missiles and automatically controls countermeasures. The AN/AAR-44 operates aboard AC-130H, AC-130U, C-130B, HC-130P/N, MC-130E, MC-130H, and C-141B aircraft. The AN/AAR-44 consists of three line replaceable units (LRUs): the control and display unit (CDU), the signal processor unit (SPU), and the sensor unit (SU). This PRAM project is concerned solely with the energy detection assembly (EDA) shop replaceable unit (SRU), contained internally within the SU. The refrigerator in the EDA at the beginning of this project was an Army Common Module cooler, rated at one watt and employing rotary technology, while the dewar was custom designed and built by Cincinnati Electronics.

During development of the AAR-44, before responsibility transitioned to WR-ALC, the dewar assembly and cryogenic cooler were recognized as reliability critical items. In the mid 1980s, we identified the cooler as evolving in technology, so we started periodic inquiries with cooler manufacturers and military users until the new linear drive technology appeared mature enough to offer a significant reliability and support cost improvement. Discussions in the fall of 1989 with the AAR-44 contractor, Cincinnati Electronics, suggested that replacing the glass detector

envelope with metal could result in further savings. Cincinnati Electronics was then hired under the PRAM program to conduct this and the following tasks.

Technical Approach

The contractor performed a detailed survey of the cryogenic coolers commercially available in order to select a cooler model best meeting system requirements, and having the best and most thoroughly verified reliability and support costs. The contractor characterized the proposed metal dewar, including heat load, to estimate its performance. Finally, the contractor updated the reliability analysis of the current AAR-44 system and extended it to include the linear cooler and metal dewar.

Conclusions and Recommendations

Characterization of the proposed metal dewar showed that its requirements for cooling could be reduced, compared to the current glass dewar, to the point a 0.25 watt cooler could be used instead of the current 1.0 watt capacity cooler. This increased the options in selecting the new linear cooler. The cooler survey resulted in selection of a Texas Instruments 2934770 model, 0.35 watt cooler.

The reliability analysis showed that the reliability is highly dependent on how the AAR-44 is used. The difficulty is that the reliability is measured in operating hours, while the dewar reliability is a function of shelf life. However, assuming the AAR-44 is used an average of 45 hours per month, then the EDA reliability would rise from 138 to 198 hours mean time between failure by adding the improvements.

Task #2 Redesign

Statement of the Problem

To implement the detector and the cryogenic cooler selected in the analysis task, it was necessary to complete the detailed design of its installation into the AAR-44.

Investigations and Findings

The detector and cooler are both in the EDA, an SRU within the SU. Therefore, we decided to make the modifications form, fit, and function compatible with the existing EDA. The design requirements were the same as the original EDA, except for the vibration environment, which was modified to take into account the gun induced vibration on gunship aircraft. Cincinnati Electronics was tasked to perform the paper design.

Technical Approach

In preparing the new design, the contractor's primary objective was to keep as much of the EDA the same, in order to preserve its original performance. However, design changes were necessary to mount the smaller cooler, the cooler electronics which were previously internal to the cooler, and to relocate the fan.

Conclusions and Recommendations

The design met the form, fit, and function criteria. Most of these criteria were of the pass/fail sort, except for the weight and center of gravity, which were improved from 39.8 to 38.0 pounds and from 0.180 inches off-center to 0.053 inches off-center.

Task #3 Fabricate and Test

Statement of the Problem

Going directly from a paper design to retrofitting the entire AAR-44 fleet would include too much risk. Risks to be reduced in this task include whether the new cooler and associated changes would physically fit in the AAR-44, whether the changes would adversely affect performance, and whether the changes would endure the AAR-44 operational environment.

Investigations and Findings

We decided the modifications were significant enough to require repeating the SU qualification testing. Since the modifications did not externally affect the SU, the tests for humidity, sand, dust, salt spray, explosive atmosphere, and shock (crash safety) were not needed. To complete the tests in a reasonable time, we required the contractor to modify three SUs.

Technical Approach

The contractor procured linear drive coolers, built detectors, and procured other needed materials, and then assembled three EDAs. The contractor then verified fit by installing them in three government SUs. The contractor then measured performance parameters including microphonic noise, heat load, and cool down time. Then the contractor performed environmental testing including vibration, temperature/altitude, and electromagnetic compatibility.

Conclusions and Recommendations

The three prototype EDAs met all requirements. As a result of testing, the contractor had some new ideas, particularly for improving maintainability; however, we judged these not significant enough to justify the additional cost.

Task #4 Documentation

Statement of the Problem

Provisions were necessary for logistic support through the lifetime of the new cooler. Because of the form, fit, and function compatibility, the changes are limited to logistics documentation.

Investigations and Findings

On review of the logistics support for the improvements, we determined that revisions were required only for reprourement data and technical orders (TOs). The changes were form, fit, and functionally all but invisible at the field level, and did not affect depot equipment because depot repair had not yet been established.

Technical Approach

The contractor produced new reprourement drawings for the EDA and all of the components that had changed, plus modified the SU drawing. The contractor produced supplements to the existing depot and field maintenance manuals, aircraft manuals, and illustrated parts breakdown. The contractor produced a new Time Compliance Technical Order for implementing the new EDA.

Conclusions and Recommendations

The documentation was completed, except government review of the TOs was not accomplished.

4. LESSONS LEARNED

Lessons Learned

Incorporation of a Linear Drive Cryogenic Cooler into the AN/AAR-44 Infrared Warning Receiver

1. Listen to your customer! Simply because a project is technically and economically sound and meets all of its objectives does not mean that it fits the customer's priorities. This project reduced reliability and life-cycle cost problems the users were willing to live with, while it had no impact on the missile warning false alarm rates they were most concerned with.
2. Items with technology insertion potential can be identified early in the system life-cycle. The cryogenic cooler was identified, at least as early as the full scale development phase, as a critical item whose reliability was undergoing technology improvement. The best technology available was applied to the production coolers, then it is a matter of monitoring the technology until it advances to the point where a retrofit would bring a worthy return on investment. We expect cooler technology to continue to advance, and plan to continue to monitor developments until they are great enough to be worthwhile to the users.
3. Using standard modular components can help a small program take advantage of broader technology trends. If the AAR-44 used a custom designed cryogenic cooler, then the cost of inserting new technology for only a hundred coolers would have been prohibitive. Instead, the AAR-44 designers chose a cooler compatible with the Army Common Module program, produced in the tens of thousands. With this broad customer base, cooler manufacturers are willing to provide new technology off-the-shelf.

5. IMPLEMENTATION

Approach

We proposed three means of implementation, none of which were accepted. The first was a retrofit of all AAR-44s. Old EDAs would be drawn from the field and modified with the improvements. This would result in the most immediate benefits and the highest initial cost. The second was attrition, where EDAs would be retrofitted as they failed. Attrition would result in the lowest up-front costs, but would delay benefits and make validation of savings difficult. The final option was to delay implementation to coincide with a package of other modifications aimed at reducing the false alarm rate. Combining with the System Improvements Program would result in costs and implementation delays somewhere between retrofitting and attrition.

Another factor influencing the implementation is our upcoming switch from contractor to Air Force depot maintenance. By timing the retrofit to coincide with this switch, the retrofit would have very little impact on depot maintenance.

We believe cryogenic cooler technology will continue to advance. Therefore, we plan to continue to monitor developments in anticipation that a future cooler will have benefits worthwhile to our customers.

Status

Throughout the project, we made numerous contacts with our customers and other interested parties. Although various individuals were quite interested in the potential for greater availability and reduced life cycle cost, the users' overriding concern was the false alarm rate (warning of a missile when there is no missile), on which this project had no impact. We were unable to achieve enough support with the users and the program office to obtain funding for a prompt retrofit. Implementation by attrition was rejected because of the paperwork involved in tracking two configurations of AAR-44 for several years. Finally, in the spring of 1994, we briefed the users on several options and costs for the System Improvements Program. The result was that the user funded most of the program to begin late FY94, but did not fund the reliability improvements.

Validation of Savings

If the cooler and dewar improvements were implemented, validation of savings would have been determined by comparing reliability data for sample periods before and after the retrofit. Cooler maintenance cost data would also have been collected, although they would not be directly comparable because EDA maintenance would have shifted from contractor to Air Force at approximately the same time as the retrofit. The other system improvements would also have been a complication, but they were not expected to significantly impact reliability. The proposed data collection periods would have been the year just prior to the retrofit, and then a year of sufficient time afterwards. Since most of the reliability drivers are life limited, a representative

life-cycle reliability could not be determined when the parts are brand new, so we would have proposed waiting at least a year after the retrofit.

6. ECONOMIC SUMMARY

The following economic analysis is based on the analysis in the project plan. The most significant change is the decrease in projected AAR-44 installs from 533 to 200, which decreases the return on investment. Another significant change is the increase in the estimate of the reliability of the SU from 138 to 153 hours MTBF.

6.1 PRAM Project Cost (PC).

Fiscal Year	Cost
1991	\$ 896,827.
1992	\$ 693,142.
1993	\$ 35,044.
Total	\$1,625,013.

The PC is the actual contractual funding obligations.

6.2 Retrofit Cost (RC)

6.2.1 Assumptions

A. A total of 200 AN/AAR-44 SUs will be installed throughout the Air Force. Presently, 101 AAR-44 systems have been purchased for installation on aircraft, at one SU per aircraft. Nearly all of these should actually be on aircraft in the next year, and for calculation purposes, the number is rounded to 100. About FY98, most of these systems will be modified to use two sensors instead of one, and it appears likely that a few new installations will be required in that time frame, so the number of install sensors is estimated to double to 200 in FY98.

B. Mr. Lee Zimmerman, a WR-ALC AN/AAR-44 equipment specialist, has estimated that 90 SUs, incorporating the new EDAs, would be purchased as spares for every 102 fielded AN/AAR-44 systems (ref. 8). When the present EDAs are used, 123 spare SUs are required for every 102 fielded AN/AAR-44 systems. To determine these spares requirements, Mr. Zimmerman relied on the D-220 Provisioning Parts List software presently used at WR-ALC to determine provisioning needs for weapons systems. His results have been reduced to the following equations:

$$\# \text{ Spare Sensor Units with new EDAs} = (0.88) \times (\# \text{ Fielded AN/AAR-44 Systems})$$

$$\# \text{ Spare Sensor Units with old EDAs} = (1.21) \times (\# \text{ Fielded AN/AAR-44 Systems})$$

C. Projected Timetable. The PRAM project ran from 1991 through 1993. If the project had been enthusiastically received, the retrofit would have started in 1993, so it is assumed that all retrofitting occurred at the end of 1993.

D. The new EDA will have successfully undergone qualification testing under Task 4 of the PRAM project. Thus, the government will be able to purchase new EDAs without spending any additional funds on testing.

E. TOs and other applicable logistical documentation covering the new EDA will have been successfully developed under Task 5 of the proposed PRAM project. Thus, implementation costs of about \$10,000 will cover the dissemination of this revised logistical documentation.

F. The new EDA will not require any additional support equipment at the organizational, intermediate, or depot levels of maintenance.

G. The 1 watt rotary drive cryogenic coolers in all current EDAs can be salvaged for \$4,000 each (ref. 9).

H. Retrofit would have included all 100 install SUs plus 90 spares, per the draft PR package for the retrofit.

I. Acquisition cost per linear cooler in 1993 was \$10,900. The planning cost to install linear coolers in 190 SUs, as expressed in the 1993 draft PR was \$9,700,000. Thus, the total not to exceed cost to modify 190 SUs is $(190 \text{ linear coolers} \times \$10,900) + \$9,700,000 = \$11,771,000$.

J. The prime contractor would provide modified SUs and organizational level maintenance personnel would accomplish the retrofit.

1. The mean time to retrofit will be 0.5 hours. (The mean time to repair (MTTR) at the organizational level is 0.5 hours, according to the AN/AAR-44 system specification).

2. The organizational level labor rate:

a. FY83: Direct Labor	\$ 7.608
Other	18.061
Total	\$25.669 (ref. 11)

b. Correcting for inflation, the organizational level labor rate will be \$32.33/hr in FY90 monies (ref. 12).

3. The organizational level material consumption rate:

FY83: Direct Material \$5.009 (ref. 11)

Correcting for inflation, the organizational level material consumption rate will be \$6.31/hr in FY90 monies (ref. 12).

K. To simplify calculations, all 100 AN/AAR-44 systems will be located in CONUS.

L. CONUS shipping rate is calculated as follows :

1. CONUS Shipping Rate - Air (Log Air): \$0.337/pound (FY85) (ref. 15)
2. Correcting for inflation, the CONUS shipping rate will be \$0.395/pound in FY90 monies (ref. 16).

M. Current EDA weight is 9 pounds, 10 ounces; this weight will be rounded up to 10 pounds. The new EDA will have the same weight as the current EDA. The SU weighs 37 pounds.

6.2.2. Calculations

A. Retrofit cost will be calculated as follows: Number of linear drive SUs needed for retrofit: 190 (ref. assumption A) Remainder of Retrofit Cost calculations:

Retrofit cost = (acquisition cost of 100 linear sensor units) + (organizational level labor and material consumption costs) + (cost of shipping new sensors to organizational levels) + (cost of shipping old sensors back to contractor) + (logistical documentation dissemination cost) - (salvage of rotary drive cryogenic coolers)

Acquisition cost of 190 new sensors: \$11,771,000 (ref. assumptions D and I)

Organizational level labor and material consumption costs = (100 install sensors) x (0.5) x [(32.33 + 6.31)/hr] = \$1,932 (ref. assumptions F and J)

Cost of shipping new sensors to organizational levels of maintenance = (190 new EDAs) x (37 pounds) x (\$0.395/pound) = \$2,777 (ref. assumptions K, L, and M)

Cost of shipping old sensors back to contractor = \$2,777
(Contractor will use parts of the old EDAs in the manufacture of the new EDAs; ref. assumptions I, K, L, and M)

Logistical documentation dissemination = \$10,000 (ref. assumption E)

Salvage of rotary drive cryogenic coolers = (190) x (\$4,000) = \$760,000 (ref. assumption H)

Retrofit cost = \$11,771,000 + \$331 + \$2777 + \$2777 + \$10,000 - \$760,000 =
\$11,026,885

6.3. Useful Life Savings (ULS). ULS will be determined by comparing the difference in acquisition and maintenance costs resulting each year from purchasing SUs with old EDAs versus purchasing SUs with new EDAs.

6.3.1. Assumptions

A. Each AN/AAR-44 system will have a useful life of twenty years (ref. 6). (Marcia Hamlin, WPAFB PRAM office, also agreed to this life span in a 14 Sep 90 phone call with Capt. Scott.)

B. Each AN/AAR-44 system will be operated an average of 45 hours/month, or 540 hours/year (ref. 6).

C. Organizational level maintenance will consist of replacing the SU at a MTTR of 0.5 hours. (The AN/AAR-44 system specification requires an organizational level MTTR of 0.5 hours.)

D. The intermediate level labor (\$32.33/hr) and material consumption (\$6.31/hr) rates are the same as the organizational level labor and material consumption rates (see assumption J under "Retrofit Cost" section).

E. Intermediate level maintenance will consist of replacing the EDA, and repairing the SUs found faulty at the organizational level. Each of these tasks will have an MTTR of 1.5 hours. (The AN/AAR-44 system specification requires an intermediate level MTTR of 1.5 hours.)

F. Depot level maintenance

1. Depot Level maintenance will normally consist of repairing the faulty SUs and EDAs; each task will have an MTTR of 8 hours.

2. Cryogenic Cooler Refurbishment and Condemnation Costs. At the 6 Sep 90 Technical Interchange Meeting (TIM), Thao Nguyen of ASD/AEME requested that the PRAM project economic analysis be revised to include refurbishment costs. As a result, the economic analysis now includes refurbishment and condemnation costs for scenarios using either the rotary or linear drive cryogenic coolers. In either scenario, depot level maintenance personnel will perform the refurbishment and condemnation tasks.

a. Linear Cryogenic Coolers. In a 9 May 90 phone call with Capt. Mark Scott, Mr. Karl Themare of CE estimated that a linear drive cryogenic cooler would last 12,000 hours before condemnation. This estimate has since been corroborated by linear cooler manufacturers (see Table 1). Depot level maintenance personnel will follow a policy of two cooler overhauls prior to condemnation, since typical linear cryogenic coolers can be refurbished at least twice (see Table 1). Thus, it is assumed that the linear coolers will be refurbished every 4,000 hours. It is assumed that depot level maintenance personnel will take about 25 hours to refurbish a linear cooler, based on information supplied by Mr. Jim Meyers, Hughes Aircraft Company, telephone (213) 517-5771, in a 7 Sep 90 telephone conversation with Capt. Mark Scott. The replacement of a condemned linear cryogenic cooler will take depot level maintenance personnel only 0.5 hours.

b. Rotary Cryogenic Coolers. In a 9 May 90 phone call with Capt. Mark Scott, Mr. Karl Themare of CE estimated that a rotary drive cryogenic cooler will last 2,400 hours before condemnation. However, this estimate assumes that the rotary cryogenic coolers are being refurbished every 800 hours. It is assumed that depot level maintenance personnel will take about 25 hours to refurbish a rotary cryogenic cooler, based on information supplied by Mr. Jim Meyers, Hughes Aircraft Company, in a 24 Sep 90 phone call with Capt. Mark Scott. Again, it will be assumed that depot level maintenance personnel can replace a condemned rotary cryogenic cooler in only 0.5 hours.

c. Average annual refurbishment and condemnation rates are calculated for both rotary and linear cryogenic coolers, noting that every third action is a condemnation.

Rotary: $540 \text{ hours per year} \div 800 \text{ hr per action} = 0.675 \text{ maint actions per year}$
 $2/3 \text{ of } 0.675 = 0.45 \text{ refurbishments per year}$
 $1/3 \text{ of } 0.675 = 0.225 \text{ refurbishments per year}$

Linear: $540 \text{ hours per year} \div 4000 \text{ hr per action} = 0.135 \text{ maint actions per year}$
 $2/3 \text{ of } 0.135 = 0.090 \text{ refurbishments per year}$
 $1/3 \text{ of } 0.135 = 0.045 \text{ refurbishments per year}$

G. The depot level labor rate (\$/hr) is calculated as follows:

1. Engineering Services, WR, FY86

Labor	\$ 17.39
Other	15.80
G&A	8.48
Total	\$ 41.67 (ref. 13)

2. Correcting for inflation, the depot level labor rate will be \$47.55/hr in FY90 monies (ref. 14).

H. The depot level material consumption rate (\$/hr) is calculated as follows:

1. Engineering Services, WR, FY86: Material \$7.20 (ref. 13)

2. Correcting for inflation, the depot level material consumption rate will be \$8.22/hr in FY90 monies (ref. 14).

I. A rotary drive cryogenic cooler costs \$15,000 (FY90 monies), while a linear drive cryogenic cooler costs \$10,000 (FY90 monies) (ref. 17).

J. In a 9 May 90 phone call with Capt. Mark Scott, Mr. Karl Themare of CE stated that a currently produced AN/AAR-44 SU costs \$133,339. The SUs produced with the new EDAs

will be assumed to cost \$128,339 in FY90 monies, reflecting the cheaper price of the new EDA, due to the linear cryogenic cooler being at least \$5,000 cheaper than the rotary cryogenic cooler (ref. 17).

K. The MTBF for the current SU is 107 hours, based on the latest D041 mean time between demand (MTBD) listing supplied by Mr. Lee Zimmerman, an AN/AAR-44 equipment specialist. Similarly, the MTBF for the current EDA is 138 hours. (The D041 MTBD data correlate very well with actual MTBF data. MTBF data from the maintenance and operational data access system (MODAS) were not used, due to the several deficiencies ascribed to that system (ref. 18).)

The data in the Reliability Prediction and Documentation of Supporting Data cannot be used directly to determine an operational MTBF for the sensor with linear cooler, however it can be used to project the proportion of improvement. The report gives failure rates for the old and new sensors, but not for the required operating hours per month, and for two different operating environments (ref. 2). Assuming that 20 percent airborne, uninhabited, attack and 80 percent airborne, uninhabited, cargo represents the fleet mix, and that the 45 hour per month usage can be calculated by linear interpolation: Failure rates per million operating hours, 20 year average:

Rotary Sensor:

20 hr per month: $80\% \times 3804 \text{ cargo} + 20\% \times 8535 \text{ attack} = 4750$

60 hr per month: $80\% \times 3042 \text{ cargo} + 20\% \times 5640 \text{ attack} = 3562$

$4750 + (3562-4750)[(45-20)/(60-20)] = 4120 \text{ fail per million hour, old sensor}$

Linear Sensor:

20 hr per month: $80\% \times 2658 \text{ cargo} + 20\% \times 5848 \text{ attack} = 3296$

60 hr per month: $80\% \times 2251 \text{ cargo} + 20\% \times 4099 \text{ attack} = 2621$

$3296 + (2621-3296)[(45-20)/(60-20)] = 2874 \text{ fail per million hour, old sensor}$

MTBF, 20 yr average, linear sensor: $107 \text{ hr} \times (4120/2874) = 153 \text{ hours}$

MTBF, 20 yr average, linear EDA: $138 \text{ hr} \times (4120/2874) = 198 \text{ hours}$

L. All procurement actions for a given fiscal year will be accomplished at the beginning of that fiscal year.

6.3.2. Calculations.

A. End of years 1 through 3 (FY94 through 97).

1. With old EDA.

a. Organizational level maintenance: (Replace sensor units; assumptions referenced)

1) Fielded sensor units: 100 (ref RC/A)

- 2) Sensor unit operating time: $(100) \times (540) = 54,000$ hours/year (ref ULS/B)
 - 3) Sensor unit failures: $(54,000) \div (107; \text{MTBF}) = 505$ failures/year (ref ULS/K)
 - 4) Repair costs: $(505) \times (0.5 \text{ hrs}) \times [(\$32.33 + \$6.31)/\text{hr}] = \$9,757$ (ref ULS/C and D)
 - 5) Shipping costs = none (Failed sensor units sent from organizational level to intermediate level for further checkout) Total: \$9,757
- b. Intermediate level maintenance: (Replace EDAs in sensor units, and repair half of sensor units turned in from the organizational level; assumptions referenced)
- 1) # fielded EDAs = # fielded sensor units = 100 (ref RC/A)
 - 2) EDA operating time: $(100) \times (540) = 54,000$ hours/year (ref ULS/B)
 - 3) EDA failures: $(54,000) \div (138; \text{MTBF}) = 391$ (ref ULS/K)
 - 4) Repair sensor units: $(505) \times (1.5 \text{ hrs}) \times [(\$32.33 + \$6.31)/\text{hr}] = \$29,270$ (ref ULS/E and F)
 - 5) Shipping costs: (Failed EDAs shipped from intermediate level to depot) (ref RC/L and M; ULS/E) EDAs: $(391) \times (10 \text{ pounds}) \times (\$0.395/\text{pound}) = \$1,544$ Total: \$30,814
- c. Depot level maintenance: (repair faulty EDAs; assumptions referenced)
- 1) Repair costs: a. EDAs: $(391) \times (8 \text{ hrs}) \times [(\$47.55 + \$8.22)/\text{hr}] = \$174,448$ (ref. ULS/F, G, and H)
 - 2) Shipping costs: (Ship repaired EDAs to intermediate level) $(391) \times (10 \text{ pounds}) \times (\$0.395/\text{pound}) = \$1,544$
 - 3) Cryocooler refurbishment and condemnation costs: (ref. ULS/F, I)
 - a) Refurbishments: $100 \times 0.45 \times (25 \text{ hrs}) \times [(\$47.55 + \$8.22)/\text{hr}] = \$62,741$
 - b) Condemnations: $100 \times 0.225 \times [(\$15,000 - \text{replacement cost; (ref. 17)}) - (\$4,000 - \text{salvage; ref RC/H}) + (0.5) \times (\$47.55 + \$8.22)/\text{hr}] = \$248,127$ Total: \$486,860
- d. Total Costs of using old EDA, each year 1 through 3 (FY94 through 97): \$527,431

2. With New EDA.

- a. Organizational level maintenance: (replace sensor units; assumptions referenced)
 - 1) Fielded sensor units: 100 (ref RC/A)
 - 2) Sensor unit operating time: $(100) \times (540) = 54,000$ hours/year (ref ULS/B)
 - 3) Sensor unit failures: $(54,000) \div (153; \text{MTBF}) = 353$ failures/year (ref ULS/K)

- 4) Repair costs: $(353) \times (0.5 \text{ hrs}) \times [(\$32.33 + \$6.31)/\text{hr}] = \$6,819$ (ref ULS/C and D)
- 5) Shipping costs = none (failed sensor units sent from organizational level to intermediate level for further checkout) Total: \$6,819

b. Intermediate level maintenance: (Replace EDAs in sensor units, and repair sensor units turned in from the organizational level; assumptions referenced)

- 1) # fielded EDAs = # fielded sensor units = 100 (ref RC/A)
- 2) EDA operating time: $(100) \times (540) = 54,000$ hours/year (ref ULS/B)
- 3) EDA failures: $(54,000) \div (198; \text{MTBF}) = 273$ (ref ULS/K)
- 4) Repair sensor units: $(353) \times (1.5 \text{ hrs}) \times [(\$32.33 + \$6.31)/\text{hr}] = \$20,459$ (ref. ULS/D and E)
- 5) Shipping costs: (failed EDAs shipped from intermediate level to depot) (ref. RC/L and M; ULS/E) EDAs: $(273) \times (10 \text{ pounds}) \times (\$0.395/\text{pound}) = \$1,078$ Total: \$21,537

c. Depot level maintenance: (repair faulty EDAs; assumptions referenced)

- 1) Repair costs: a. EDAs: $(273) \times (8 \text{ hrs}) \times [(\$47.55 + \$8.22)/\text{hr}] = \$121,802$ (ref ULS/F, G, and H)
- 2) Shipping costs: (Ship repaired EDAs to Intermediate Level) $(273) \times (10 \text{ pounds}) \times (\$0.395/\text{pound}) = \$1,078$
- 3) Cryocooler refurbishment and condemnation costs: (Ref Table 2; ULS/F, I)
 - a) Refurbishments: $100 \times 0.090 \times (25 \text{ hrs}) \times [(\$47.55 + \$8.22)/\text{hr}] = \$12,555$
 - b) Condemnations: $100 \times 0.045 \times [(\$10,000 - \text{replacement cost; (ref. 17)}) - (\$4,000 - \text{salvage; ref RC/G}) + (0.5) \times (\$47.55 + \$8.22)/\text{hr}] = \$27,125$ Total: \$162,560

d. Total Costs of using new EDA, each year 1 through 3 (FY94 through 97): \$190,913.

B. End of year 4 (FY98).

1. With Old EDA.

a. Maintenance: Same as years 1 through 3, \$527,431

b. Procurement Actions:

Purchase 100 sensor units for installation for a total of 200 installs (ref. RC/A)

Number of spares required $200 \times 1.21 = 242$ sensors

Total of $200 + 242 = 442$ sensors required, purchase $442 - 190 = 252$ sensors (ref. RC/B)

Cost of procurement: $252 \times \$133,339 = \$33,601,428$ (ref ULC/J)

c. Total Costs of using old EDA, year 4 (FY98):\$34,128,859.

2. With New EDA.

a. Maintenance: Same as years 1 through 3, \$190,913

b. Procurement Actions: Purchase 100 sensor units for installation for a total of 200 installs (ref. RC/A)

Number of spares required $200 \times 0.88 = 176$ sensors (ref. RC/B) Total of 200

+176 = 376 sensors required, purchase $376 - 190 = 186$ sensors

Cost of procurement: $186 \times \$128,339 = \$23,871,054$ (ref ULC/J)

c. Total Costs of using new EDA, year 4 (FY98): \$24,061,967

C. End of each year 5 through 20 (FY99 through 13).

1. With Old EDA.

Maintenance: Since installs have doubled from years 1 through 3, then annual maintenance costs have doubled to a total of \$1,054,862

2. With New EDA.

Maintenance: Since installs have doubled from years 1 through 3, then annual maintenance costs have doubled to a total of \$381,826

6.4. Summary of Useful Life Savings (ULS) for years 1-20 (FY94 - FY13).

Year (FY)	Using Old EDAs	Using New EDAs	ULS
	(Old)	(New)	(Old-New)
1 (94)	527,431.	190,913.	336,518.
2 (95)	527,431.	190,913.	336,518.
3 (96)	527,431.	190,913.	336,518.
4 (97)	527,431.	190,913.	336,518.
5 (98)	34,128,859.	24,061,967.	10,066,892.
6 - 20	1,054,862.	381,826.	673,036.
Total	52,061,513.	30,553,009.	21,508,504.

6.5. Return on Investment (ROI). It should be noted that, although the PRAM project cost is included in the ROI, the PRAM project is now a sunk cost and should not be considered in deciding whether to continue with the implementation.

$$\text{ROI} = \text{ULS} \div (\text{PC} + \text{IC})$$

A. ULS = \$21,508,504

B. PC = PRAM project cost = \$1,625,013

C. IC = Implementation Cost = Retrofit Cost = \$8,662,685

D. ROI = 2.1

6.6. Analysis.

6.6.1. Over a 20-year period, the implementation of this project would result in increased survivability for those aircraft carrying AN/AAR-44 systems, as well as a government savings of over \$21,000,000. These benefits are due to the following reasons:

A. SUs equipped with the new EDAs are cheaper than SUs equipped with the old EDAs.

B. SUs using the new EDAs require fewer spares.

C. SUs equipped with the new EDAs have lower organizational, intermediate, and depot level maintenance costs.

D. Linear cryogenic coolers are more reliable than rotary cryogenic coolers.

6.6.3. Unquantifiable savings.

Since the dewar in the present EDA is currently made of glass, a significant potential for breakage exists at the depot level. Thus, the depot will save money by using the modified EDAs with their metal dewars.

REFERENCES

1. "The Sterling Cycle - The Forerunner of Today's Technology". 2-page informational handout by Hughes Aircraft Company, Electron Dynamics Division, 3100 West Lomita Boulevard, P.O. Box 2999, Torrance, CA 90509-2999. Not dated.
2. Incorporation of a Linear Drive Cryogenic Cooler Into the AN/AAR-44 Infrared Warning Receiver, Reliability Prediction and Documentation of Supporting Data 16 Sep 1992, Cincinnati Electronics Corp, Cincinnati OH.
3. Mr. Dave Giguere, Product Sales Manager, Thermal Products Division, Hughes Aircraft Company, (213) 517-5771, in a 27 Apr 90 telephone conversation with Capt. Mark Scott.
4. Mr. Jim Meyers, Thermal Products Division, Hughes Aircraft Company, (213) 517-5771, in a May, 1990 telephone conversation with Mr. John Fitzpatrick, CE.
5. Mr. Grant J. Milbouer, Marketing Product Manager, Cryogenic Coolers, Electro-Optical Systems Division, Magnavox, (201) 529-1700, in a 27 Apr 90 telephone conversation with Capt. Mark Scott, WR-ALC/MMRRIS.
6. Estimate by Capt. Wayne McClary, AFECO/EX, DSN 785-2271, in an 8 May 90 telephone conversation with Capt. Mark Scott, WR-ALC/MMRRIS. Capt. McClary briefed "Life-Cycle Cost Analysis of Missile Warning Systems (AAR-44 and AAR-47)" to WR-ALC/MMH on 15 Feb 90.
7. Estimate by Capt. Wayne McClary, AFECO/EX, in a 9 May 90 telephone conversation with Capt. Mark Scott, WR-ALC/MMRRIS.
8. Mr. Lee Zimmerman, WR-ALC/MMRRSB, in a telephone conversation with Capt. Mark Scott, WR-ALC/MMRRIS, on 9 May.
9. Mr. Dennis Allen, CE, in a 7 May 90 telephone conversation with Capt. Mark Scott, WR-ALC/MMRRIS.
10. Mr. Dennis Allen, CE, in a 10 May 90 telephone conversation with Capt. Mark Scott, WR-ALC/MMRRIS. The new EDA would be about 10% cheaper than the old EDA, since the new EDAs will use several parts from the current EDAs; such as the outer covers and other external segments. The old EDAs presently cost \$55,103 in FY90 monies.
11. Figure 2-6: "Average Base Maintenance Rates (Per Direct Labor Hour)", AFLCP 173-10, 30 May 86.

12. Table A45-7: "USAF Raw Inflation Indices". Base year FY90, going back to FY83: 0.794 (O&M/Non-Pay). AFR 173-13, Attachment 45, 31 Oct 89. Thus, (FY83 value) \cdot (0.794) = FY90 value.

13. Figure 2-1, AFLCP 173-10, 30 May 86.

14. Table A45-3: "USAF Raw Inflation Indices". Base year FY86 to FY90: 1.141 (O&M/Non-Pay). AFR 173-13, Attachment 45, 31 Oct 89. Thus, (FY86 value) \times (1.141) = FY90 value.

15. "FY85 Transportation Cost Factor (Cost Per Pound)". AFLCP 173-10, 30 May 86. Page 18.

16. Table A45-2: "USAF Raw Inflation Indices". Base year FY85 to FY90: 1.173 (O&M/Non-Pay). AFR 173-13, Attachment 45, 31 Oct 89. Thus, (FY85 value) \times (1.173) = FY90 value.

17. According to Mr. Ward Fleshman, CE, in a 6 Sep 90 conversation with Capt. Mark Scott, WR-ALC/MMRRIS, Hughes recently quoted a price of \$15,244 for their rotary drive 7004H model. Mr. Karl Themare, CE, in a 9 May 90 telephone conversation with Capt. Scott, had reported that a rotary cooler had a price of \$11,000. The cost increase is due to increased labor and material costs. A CTI-Technologies rotary cooler would similarly cost about \$15,000, since it uses the same controller circuitry. The worst-case price for a typical linear cooler, when purchased in lots of 100, is \$10,000.

18. Colt, David W., Russell, David L., and Russ O. Wisley. Reliability/Maintainability Operational Parameter Translation II: Final Report. Volume I. December, 1989. Prepared for the Rome Air-Development Center, Air Force Systems Command, Griffis Air Force Base, NY, by the ITT Research Institute, Beeches Technical Campus, Route 26N, Rome, NY.

According to Colt, et. al.:

Initial consideration was given to using MODAS as the primary source of R/M [reliability/maintainability] data. The MODAS system was rejected due to several deficiencies. Problems with MODAS were determined to be:

- 1) Operating hours are not recorded
- 2) Depot repair activity is not properly documented
- 3) Failures are not verified
- 4) Reported errors have been identified
- 5) Accessing the system is inefficient for large and detailed data requests.

7. APPROVAL AND COORDINATION

OFFICE SYMBOL	SIGNATURE	DATE
Project Engineer	<u>David Farnier</u>	<u>31 Oct 94</u>
LNxEA	<u>Larry M Sheets</u>	<u>11-3-94</u>
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SES	<u>Jack M. McFarland</u>	<u>9 Nov 94</u>
PRAM Manager	<u>Thomas A. Allen</u>	<u>27 Oct 94</u>
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TIEC	<u>Stanley K. Tubey</u>	<u>17 NOV 94</u>
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